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EVALUATION OF TWO DIMENSIONAL
ADAPTIVE ANTENNA ARRAYS

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The objective of the research reported here is to evaluate the improvement in HF antenna array performance achievable through adaptive processing under actual field conditions, emphasizing two dimensional array geometries. The approach has been to collect experimental data under a variety of propagation conditions and evaluate the performance of the array with and without adaptive beamforming. A two-dimensional HF phased array facility had been established at Hudson, Colorado in connection with other ARPA programs and this facility was modified for adaptive data taking. The modification included the

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This interim report describes the modified phased array facility and presents an example of the results now being obtained. The adapted sky map is in fact found to be very much improved over the map generated from the same data by conventional beamforming methods: spurious responses from sidelobes are virtually eliminated and the angular resolution is significantly greater. The significance for DOD systems is that a technique is available for significantly improving the performance of HF radar and surveillance systems at the cost of increased processing load.

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This report has been reviewed by the RADC Information Office, OI, and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved.

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EVALUATION OF TWO DIMENSIONAL ADAPTIVE ARRAYS

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Summary

Conventional beamforming methods for HF antenna arrays are non-adaptive in that the outputs from each element are combined without regard for the particular distribution of signals incident on the array. It has been found in sonar and seismic research that superior array performance can be realized if the beamforming operation is continuously adapted to the signal environment and several algorithms for accomplishing this have been developed. The performance improvement has been particularly striking in situations where sidelobe levels and angular resolution would be unsatisfacotry with conventional beamforming. These are problems frequently met at HF and this has motivated the search for improved performance of HF antenna arrays through adaptive beamforming.

The objective of the research reported here is to evaluate the improvement in HF antenna array performance achievable through adaptive processing under actual field conditions, emphasizing two dimensional array geometries. The approach has been to collect experimental data under a variety of propagation conditions and evaluate the performance of the array with and without adaptive beamforming. A two-dimensional HF phased array facility had been established at Hudson, Colorado in connection with other ARPA programs and this facility was modified for adaptive data taking. The modification included the construction of 32 modular receivers and a 32 element cross array of vertical monopoles. Data were recorded on digital tape and processed off-line to produce sky maps (signal strength versus azimuth and elevation) in the full bandwidth of the receivers (17 kHz).

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virtually eliminated and the angular resolution is significantly better. . The significance for DOD systems is that a technique is available for significantly improving the performance of HF radar and surveillance systems at the cost of increased processing load.

The final report will present results under a variety of conditions, will discuss rate at which adaptation must take place in order to keep up with changes in the environment, and will document the software developed and used in this program.

Introduction

In HF antenna arrays, as in sonar and seismic arrays, a central problem is how to combine the outputs from individual elements in the array to give the best description of the incident wave field. One of the important developments in this area has become known as adaptive processing and has been applied with great success to sonar and seismic arrays.

The work reported here is part of a DARPA program to evaluate the benefits to be gained by applying adaptive processing techniques to HF antenna arrays and the practicality of doing so. Both the benefits derived and the magnitude of the processing task depend critically on the characteristics of the environment in which the array operates, making data collection under realistic field conditions an essential part of the evaluation. The Raytheon component of the program involved modification of an existing HF antenna facility in Hudson, Colorado to provide data on a large two-dimensional array in a format appropriate for adaptive processing. Data collected at this facility was then reduced and evaluated. A parallel effort at the Stanford Research Institute (SRI) gave data on a large one-dimensional array (the WARF antenna). The University of Colorado task included algorithm development and also participation in the data reduction.

This report is an interim report describing the Raytheon effort and giving an example of the benefits of adaptive processing over conventional processing in the actual HF environment. The final report will contain the bulk of the data and will discuss the significance of the results.

The Hudson HF Phased Array Facility

The Hudson HF phased array facility was established in support of earlier ARPA programs and modified under the current program for collecting data in a format which lends itself to adaptive processing. Prior to modification the facility consisted of a 32 element array of horizontal crossed dipole elements equally spaced about the circumference of a 600 meter ring, 32 phase-coherent receivers with sample and hold circuits in each receiver, and a digital data handling system for a quick-look field analysis and for recording the raw data on magnetic tape for later processing. The modifications made to the facility include the following:

a) Fabrication and installation of 32 additional receiver modules to provide quadrature outputs from each antenna element and unambiguous mapping of incoming signals.

b) Fabrication of 32 vertical monopoles and coupling amplifiers to permit mapping of low elevation angle signals.

c) Installation of the monopoles to form a cross array (32 elements, 300 meter north-south and east-west aperture).

An artists' sketch of the facility as it now exists is shown in Figure 1. Only the cross array has been used for adaptive data collection. A plan view of the site with dimensions is shown in Figure 2 and a block diagram of the electronics is shown in Figure 3.

The bandwidth of the receivers is 17 kHz and all receivers are sampled simultaneously at a rate which can be varied from 2 to 250 Hz. Quadrature channels allow unambiguous amplitude and phase measurements for each element for each sample of the array even though the sampling rate is well below that required to unambiguously examine the doppler spectrum across the full bandwidth of the receiver.

Data Collection

The modified Hudson facility has been used to collect data representing the HF environment under a variety of conditions. Data have been taken in the amateur bands and in the International broadcast bands to represent a heavy interference environment. Data under more controlled conditions have been taken using transmissions provided by SRI from their field site at Lost Hills, California. In these measurements the frequency could be adjusted to control the

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SHORT CROSSED DIPOLE
RECEIVING ELEMENT

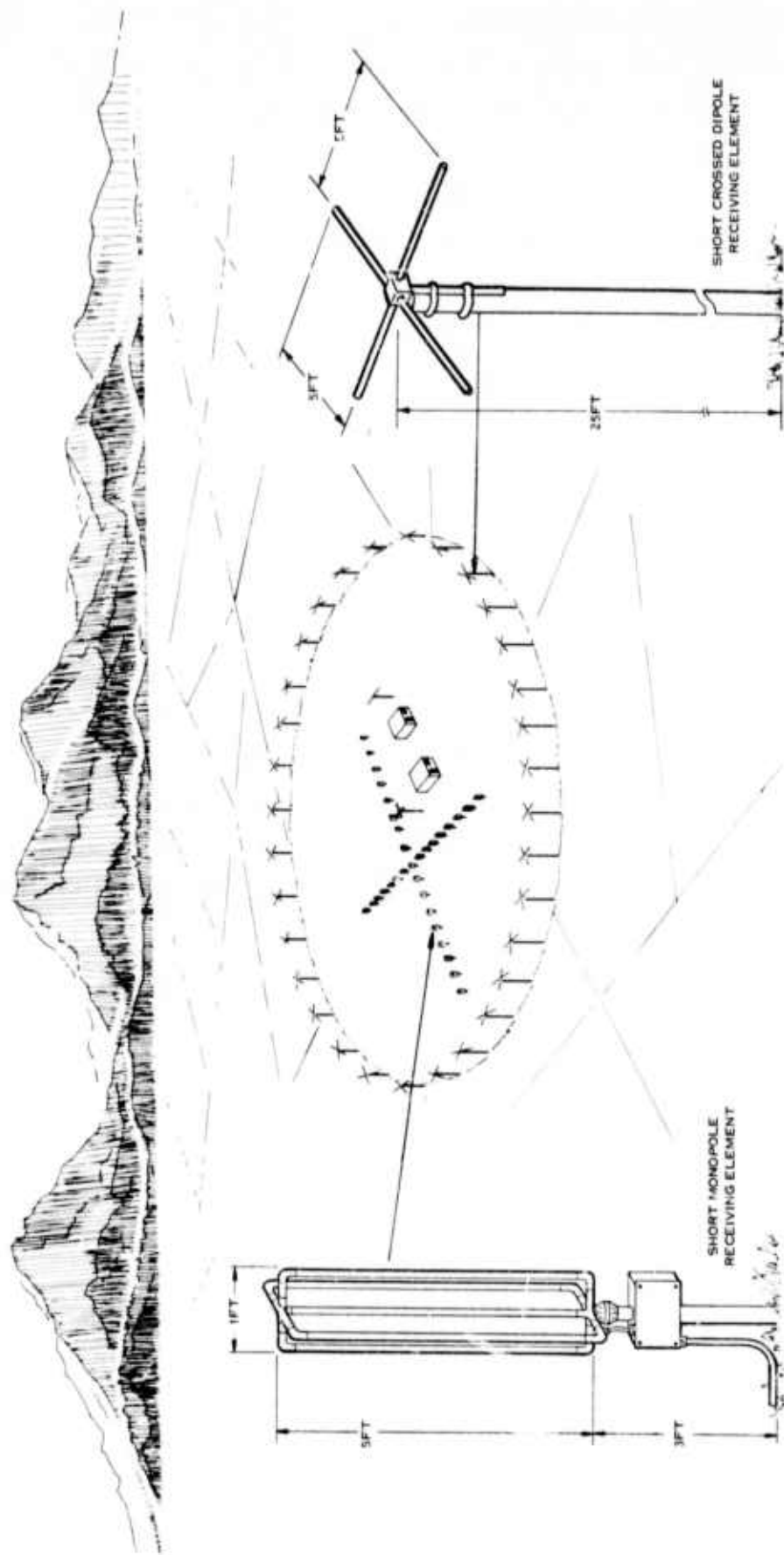SHORT MONOPOLE
RECEIVING ELEMENT

Figure 1: A perspective view of the HF phased array facility at Hudson, Colorado. The legs of the cross array run north-south and east-west. North is to the upper right.
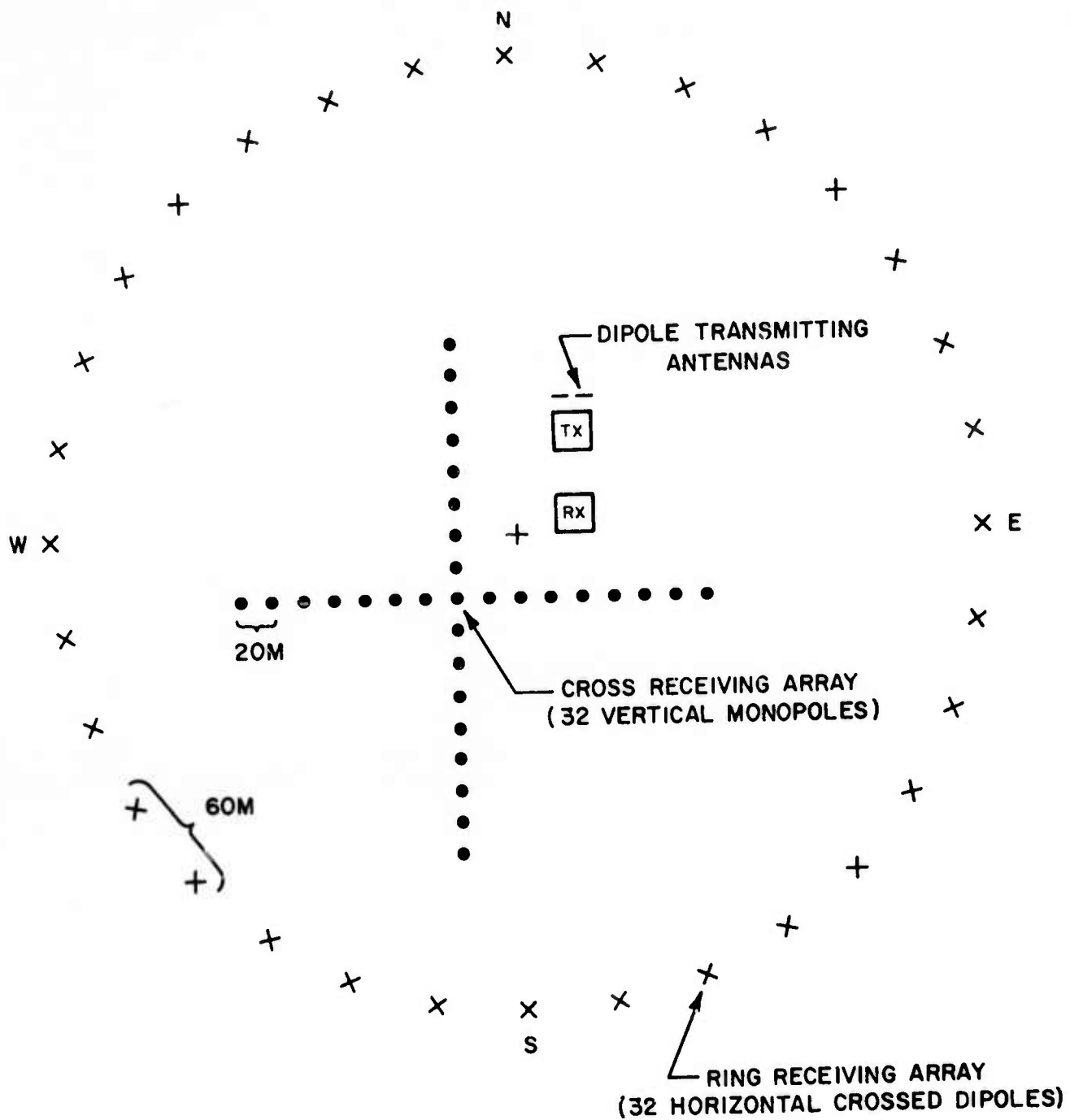
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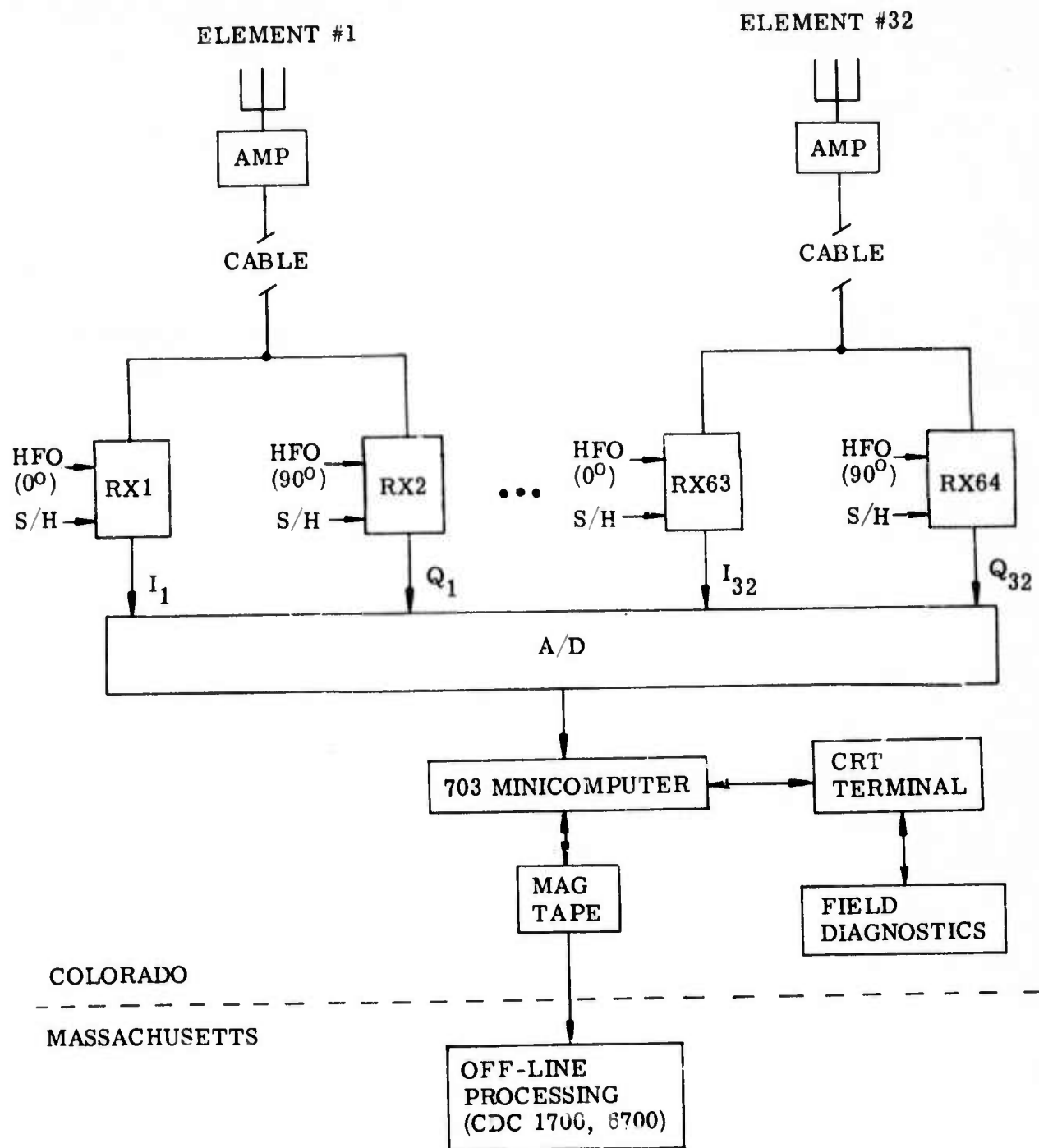Figure 2: A plan view of the Hudson phased array facility.

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Figure 3: A block diagram of the electronics at the Hudson phased array site used for adaptive data taking.

number of modes propagating and the power could be varied to control the signal to noise ratio. An example of data collected under single-hop, high signal to noise ratio conditions is given below.

Results

The data to be discussed was collected over the path shown in Figure 4. The frequency was 15.7 MHz. The monthly median ionogram shown in Figure 5 illustrates ionospheric conditions expected for this path during this month and at the time of day of interest. This ionogram has been used to calculate the mode plot shown in Figure 6 giving the angle of arrival of the various modes which are allowed at this frequency as a function of distance. The SRI field site is 1433 km from Hudson and for this distance two modes are permitted, a high angle one hop F_2-region mode (1F2H) arriving at an elevation angle of about 30° and a low angle one hop F_2-region mode (1F2L) arriving at an elevation angle of about 15°. Propagation paths for these modes are sketched in Figure 7.

Sky maps produced from 1 second of data using conventional and adaptive beamforming methods are compared in Figure 8. By conventional beamforming we mean an algorithm in which the power arriving from a given direction is estimated by introducing appropriate phase shift in the signal from each element before combining so that the signals from all elements would add in phase for a plane wave arriving from that direction. That is, weights are applied to each element which change the phase of the signal but not the amplitude. By adaptive beamforming we mean an algorithm in which both the amplitude and phase of the weights are chosen on the basis of the signals actually observed at the elements so as to optimize the power estimate in a given direction. The specific algorithm we have used to accomplish this is equivalent to that described by Capon[1] and further discussion of the mathematics will be deferred until the final report.

The sky map produced by conventional beamforming reveals only one signal (the dominant, low-angle mode arriving at about 225° azimuth and 20° elevation): the weaker high-angle mode is lost in the sidelobes of the dominant mode. In contrast, both modes are clearly revealed in the map produced by adaptive beamforming. Further, the effective beamwidth of the adapted map is very much better than that of the conventional map.

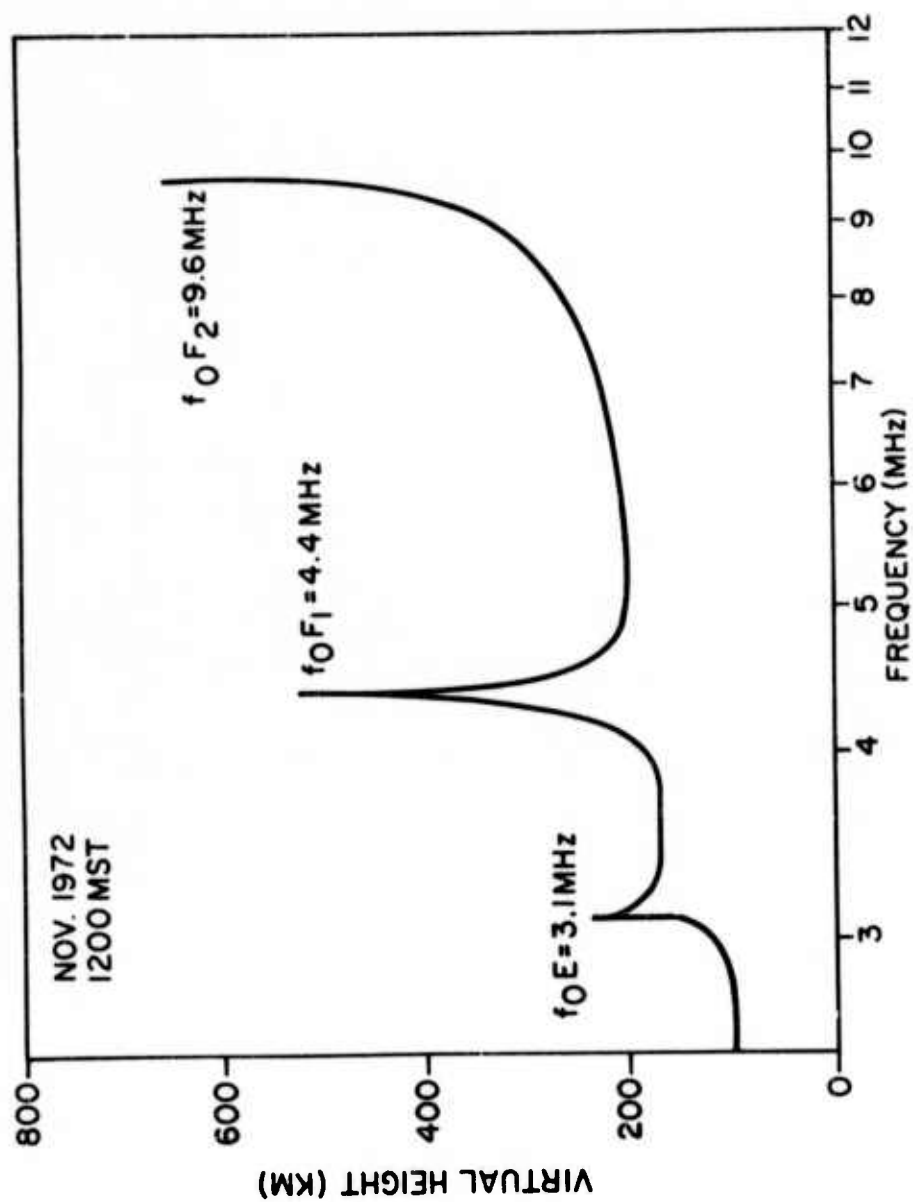Figure 4: Test geometry for adaptive data taking with cooperative transmitter.

HUDSON, COLO.
(RAYTHEON) RX

1433 KM
254.5° AZ

LOST HILLS, CA.
(SRI) TX

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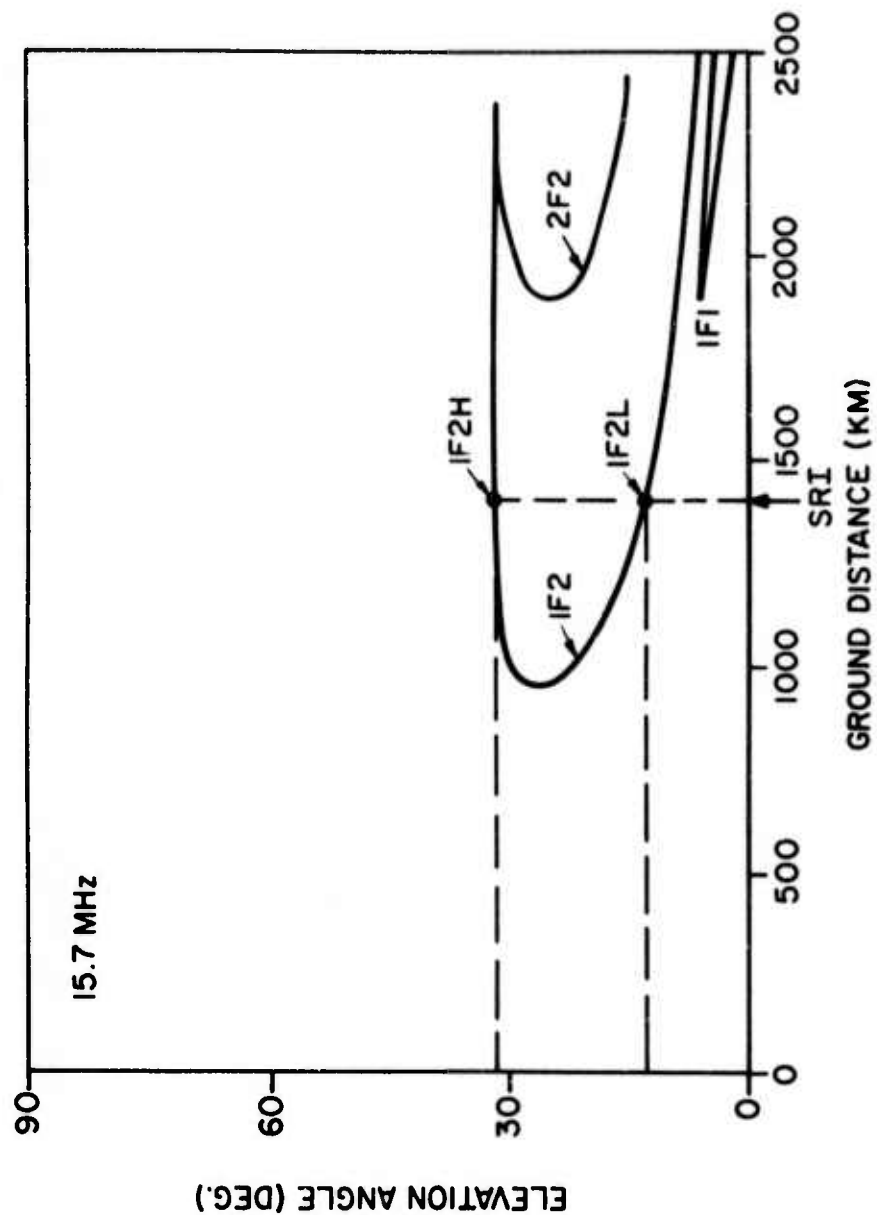Figure 5: Ionogram representing ionospheric conditions during cooperative data taking experiments.

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Figure 6: Mode plot showing that 15.7 MHz two F_2-region modes should propagate from SRI to Hudson, a 1 hop high angle ray (1F2H) and a 1 hop high angle ray (1F2H) and a 1 hop low angle ray (1F2L).
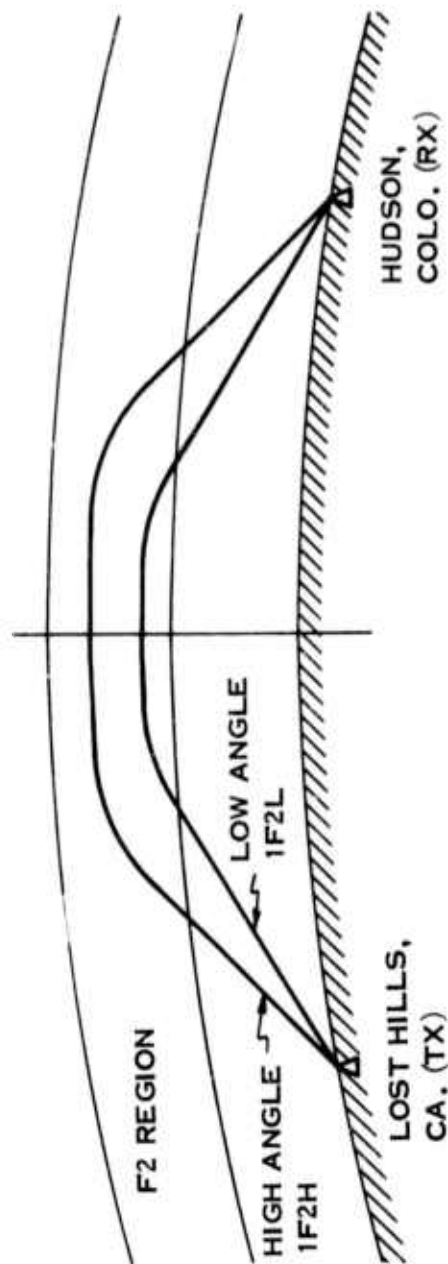
Figure 7: Sketch showing the ray paths fro the modes expected between SRI and Hudson under test conditions.
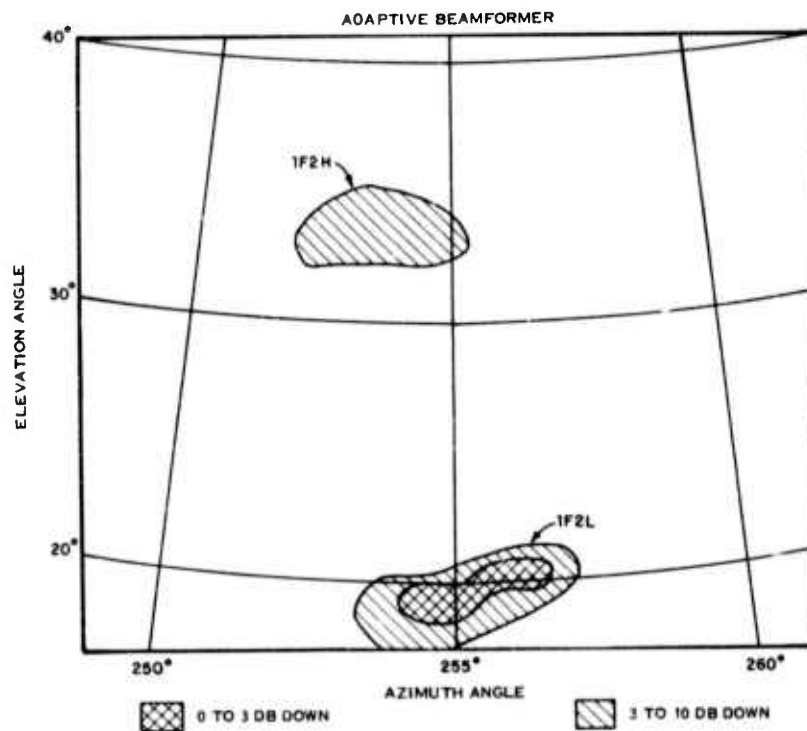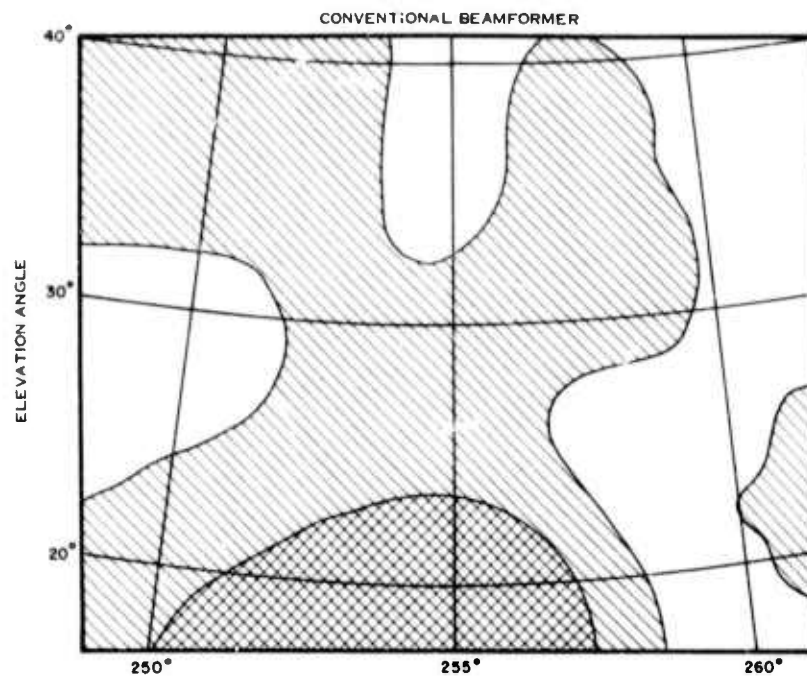
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Figure 8: A comparison of sky maps generated from the same 1 second of data with conventional beamforming (top) and with adaptive beam-forming (bottom). The adaptive map provides superior angular resolution and reveals a weak mode which was masked by side-lobes with conventional beamforming.

Conclusions

It has been shown that adaptive processing can be an effective means of enhancing the performance of HF antenna arrays. It remains to be shown that a significant improvement is realized over a wide range of environmental conditions: also it remains to be shown that the environment changes slowly enough so that the task of recomputing weights to keep the beamformer near optimum will not be prohibitive in real-time applications. These questions will be addressed in the final report.

Reference

Capon, J., High-Resolution Frequency-Wavenumber Spectrum Analysis, Proc. IEEE, Vol. 57, No. 8, 1969.

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